80th ANNIVERSARY OF **PARÍCUTIN** VOLCANO

FIELDTRIP GUIDE

GEOHERITAGE OF XITLE VOLCANO, MEXICO CITY

Leaders: Marie-Noëlle Guilbaud, María del Pilar Ortega-Larrocea, Silke Cram Heydrich and Alejandro Pastrana Cruz.

Instituto de Geofísica
UNAM

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"Geoheritage of Xitle volcano, Mexico City"

Fieldtrip guide

"Celebrating the 80th anniversary of Paricutin volcano, preserving our heritage and preparing for future eruptions"

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ABSTRACT

This fieldtrip guide has the principal objective to support the organization of visits to major geosites related to Xitle volcano in the SW sector of Mexico City. We adopt a multi-disciplinary approach that reveals the very diverse and rich heritage that this region of Mexico City holds. The guide is based on years of collaborative studies at these sites, including the organization of several excursions. It is our ambition that, because of the diverse type of information (geological, biological, pedological and cultural) that this guide contains, it can appeal to visitors with distinct interest and background. This guide may be also of use for professors or students looking for general information on the Xitle volcano. The excursion as described in this guide first took place on Thursday 16 – Saturday 18, February 2023, prior to the international conference commemorating the 80th anniversary of the Paricutin eruption, where it was evaluated favorably by the participants. Part of the information was updated from a previous publication in the Geoheritage journal (Guilbaud *et al.*, 2021).

INTRODUCTION

The Xitle volcano, in the south of Mexico City, consists of a small scoria cone (140 m high, 500 m wide) and a vast lava field (*ca.* 80 km^2) that were produced by a single basaltic eruption which was dated at 1670±35 years before present or AD 245-315 (Delgado *et al*., 1998; Siebe, 2000). The volcano erupted at 3000 m asl, on the N flank of the Sierra Chichinautzin Volcanic Field located in the central-eastern part of the subduction-related Trans-Mexican Volcanic Belt (Figure 1). The Sierra Chichinautzin Volcanic Field borders the south of Mexico Basin (Figure 1) and consists of more than 200 small volcanic edifices, most of them scoria cones and lavas (e.g., Bloomfield, 1975; Martín del Pozzo, 1982; Márquez *et al.*, 1999; Siebe, 2000; Arce *et al*., 2013).

The chronology of the eruption is only partly known (Delgado *et al*., 1998; Siebe, 2000). After an initial explosive phase that produced tephra, the volcano emitted lavas that flowed down into the SW part of the Mexico basin, burying most of a pre-Hispanic settlement (Cuicuilco) and reaching the shores of the ancient Xochimilco and Texcoco lakes at *ca.* 2250 m asl, 12 km from source.

The lava field is complex and consists of multiple units, indicating a pulsing effusive activity punctuated by minor explosive phases. The large volume erupted (>1 km^3) suggests that the eruption lasted a decade or more (Guilbaud & Siebe, 2009). Lavas are mostly of pahoehoe type and form barren, rocky land with irregular topography. The vegetation of the Xitle lava field has been mapped by Carrillo-Trueba (1995), revealing a diverse plant pattern that varies mostly with altitude. While high-standing areas (>2500 m asl) near the vent are dominated by forests of pine tree, oak and fir, low-altitude areas (<2500 m asl), in the distal lava field, are covered by a xeric scrub dominated by Pittocaulon praecox that is native to Central Mexico (Rzedowski, 1954).

The lavas were mostly left un-populated until the central campus of the National University of Mexico (UNAM) was built in 1948-1952 on the far end of the flow (Figure 1; Carrillo-Trueba, 1995; Salas Portugal, 2006). By now, the city has incorporated almost the entire lava field, except for a few patches, which are fragmented and at risk of disappearing due to real-estate pressure (Cano-Santana *et al*., 2006). The largest and best conserved of these patches is the "Reserva Ecológica del Pedregal de San Angel" or REPSA, an urban reserve with a core zone of 171 ha and a buffer zone of 66 ha that was created in 1983 inside UNAM, after an environmentalist movement lead by students and academics (http://www.repsa.unam.mx; Zambrano *et al*., 2016). Although the central part of the UNAM campus was included in UNESCO's World Heritage List in 2007 (UNESCO, 2007), the natural heritage of the campus has not received the acknowledgement it deserves. About 660,000 people currently live on the lava field (Hernández-Robles, 2019), most of them without knowing that they live on a young bed of volcanic origin.

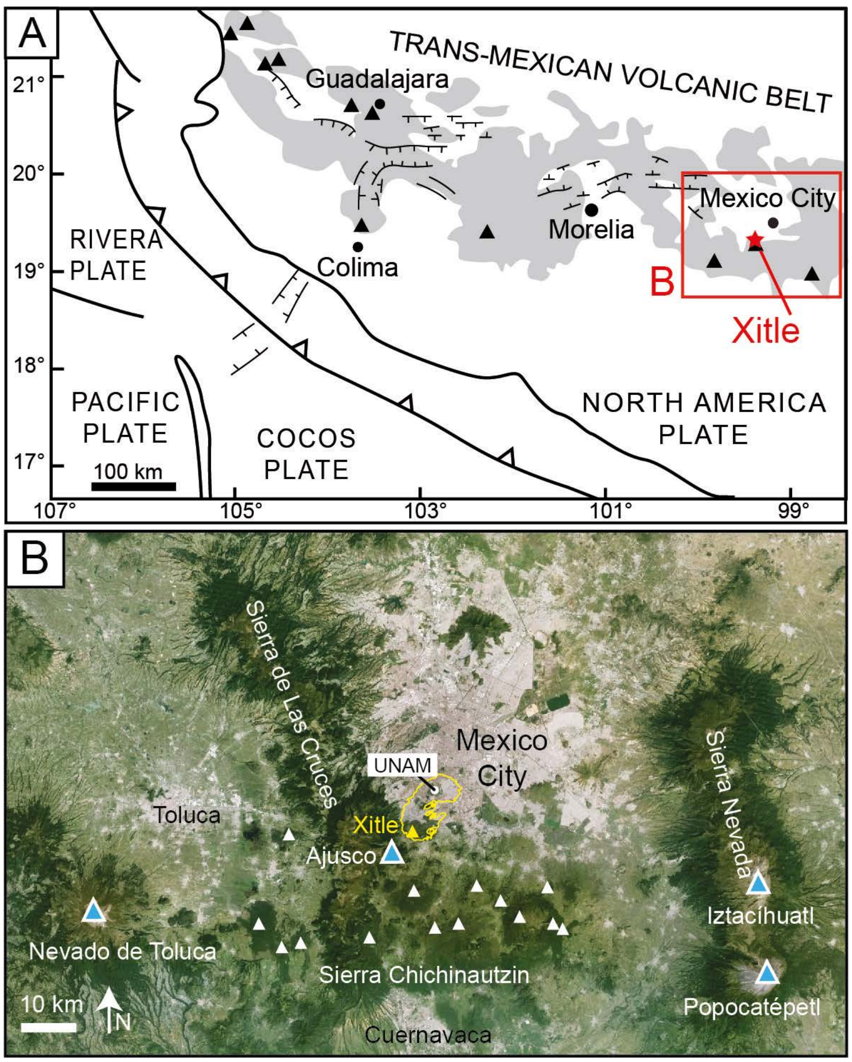

Figure 1: A. Localization of the Xitle volcano and Mexico City in the Trans-Mexican Volcanic Belt and associated arc-type tectonic system. Dark triangles indicate major stratovolcanoes along the belt. Black points indicate main cities with millions of inhabitants. Note that most of these are located in the volcanic belt and hence at risks from new and ongoing eruptions. B. Localization of Xitle volcano (yellow triangle) and Xitle lava field (yellow polygon) that includes the UNAM campus, in the SW corner of the Mexico Basin host to Mexico City. White triangles are volcanoes of the Sierra Chichinautzin formed during the last 17,000 yrs (compilación de: Bloomfield, 1975; Siebe *et al*., 2004; Siebe *et al*., 2005; Agustin-Flores *et al*., 2011; Guilbaud *et al*., 2015; Lorenzo-Merino *et al*., 2018). Blue and white triangles are stratovolcanoes. Popocatepetl has been in eruption since 1994, while the Nevado de Toluca´s last large eruption occurred 10,500 yrs ago (Arce *et al*., 2003). Ajusco is extinct (modified from Guilbaud *et al*., 2021).

GEOSITE DESCRIPTION

In this excursion, we will visit four exceptional geosites linked to the Xitle volcano that have high scientific and cultural values and are relevant for addressing issues such as nature preservation, environmental sustainability, social inequalities, and natural hazards (Guilbaud *et al.*, 2021). The geosites are located on Figure 2 along with the main roads that allow access to them. Other interesting sites that may be visited (see localization and descriptions in Palacio and Guilbaud, 2015) are also indicated.

Day 1: Xitle cone geosite

The area of the Xitle cone is where the volcanic products (lava and tephra) were emitted during the eruption. This is a pleasant, green zone that is easily accessible from the city. The position of the main cone on an elevated plateau directly S of the city offers panoramic views of the Mexico basin and of the surrounding volcanoes that are both aesthetic and instructive. The walking paths are easy and do not require specific equipment. Note however the relatively high altitude (*ca*. 3000 m asl, compared to 2268 m asl for the UNAM campus) and the occasional occurrence of a cold breeze.

This site displays typical proximal products of weakly-explosive, Hawaiian and Strombolian-style basaltic activity that are particularly well preserved and exposed and are characteristic of monogenetic volcanism. The vent area consists of a scoria cone (Xitle proper) and a spatter and lava cone (Xicontle) that are aligned in a broad WSW-ENE direction, suggesting a fissure (Figures 3A, 3B). The vegetation in the vent area follows a pattern that matches the distribution of the volcanic morphological elements (cone, crater, lava). Each of them present distinct soil types and microenvironments due to variations in altitude and sun exposure (Figure 3C). The dominant tree species are endemic of Central Mexico.

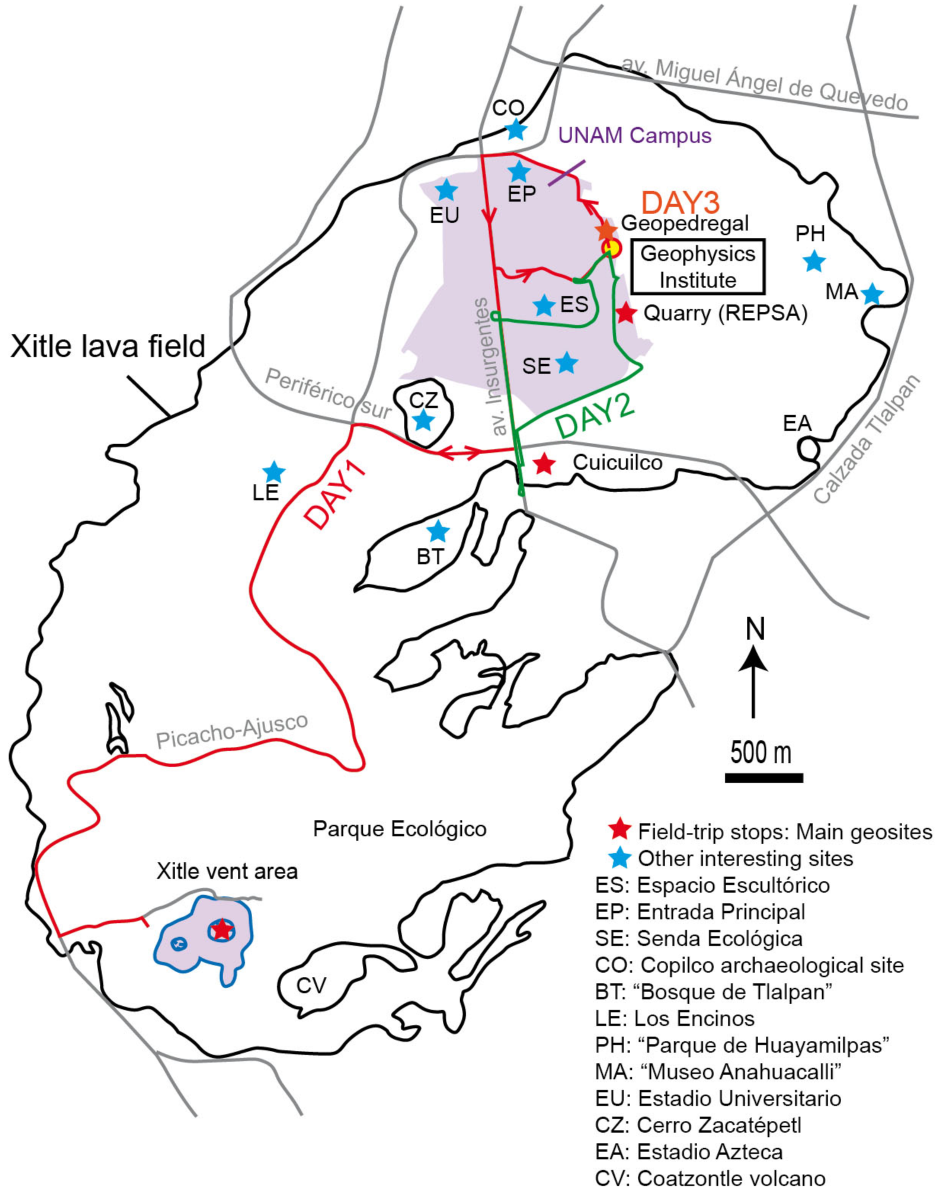

Figure 2: Map of Xitle lava field with the location of the field trip stops and itinerary for each day, reference points in the city, and the main roads. The circle filled in yellow indicates the location of the Geophysics Institute that is near the terminal metro station "Universidad" (green line).

Itinerary and description of stops:

The excursion starts along the road named "camino al crater" located in the "colonia Héroes de 1910 (Tlalpan)", at about 1 h drive from the UNAM campus (Figure 2). The entire excursion (path shown on Figure 3) takes about 3 to 4 hours and include the time at the stops for discussions and refreshments.

Stop 1: Xicontle crater(GPS: N19°14.745', W99°13.670', 3042 m asl).

After a walk on a steep slope of *ca.* 15 min, we get to the rim of the Xicontle crater where there is a view to the interior and the superposition of spatter layers and thin (<1 m) lavas can be observed (Figure 4). These products are emitted by lava fountaining that typically occur during weak explosive activity along fissures. From this location, the northern slope of the Ajusco stratovolcano can also be seen (Figure 4). This volcano is considered extinct and was affected by sector collapse and the emplacement of a debris avalanche deposit with its typical hummocky morphology. This deposit was subsequently mostly covered by the Xitle lavas but some hummocks still outcrop, such as the Cerro Zacatepetl (Cervantes & Molinero 1995). The Xitle cone can also be observed from this site looking to the ENE. Near to it, there is a firefighter station that monitors wildfires in this forested area that commonly occur in the driest part of the year (April-May).

Stop 2: Soil formation and vegetation on cone (GPS: N19°14.751', W99°13.428', 3077 m asl).

We follow the walking path that comes down on the N slopes of Xicontle and climb up the W slopes of Xitle cone (Figure 3A), and passes by an area of illegal population settlement. The path going up the Xitle cone present vertical exposures of tephra covered by a soil (Figure 5A). The tephra is mostly lapilli in size (cm-size fragments) and the most vesicular clasts show some sign of alteration

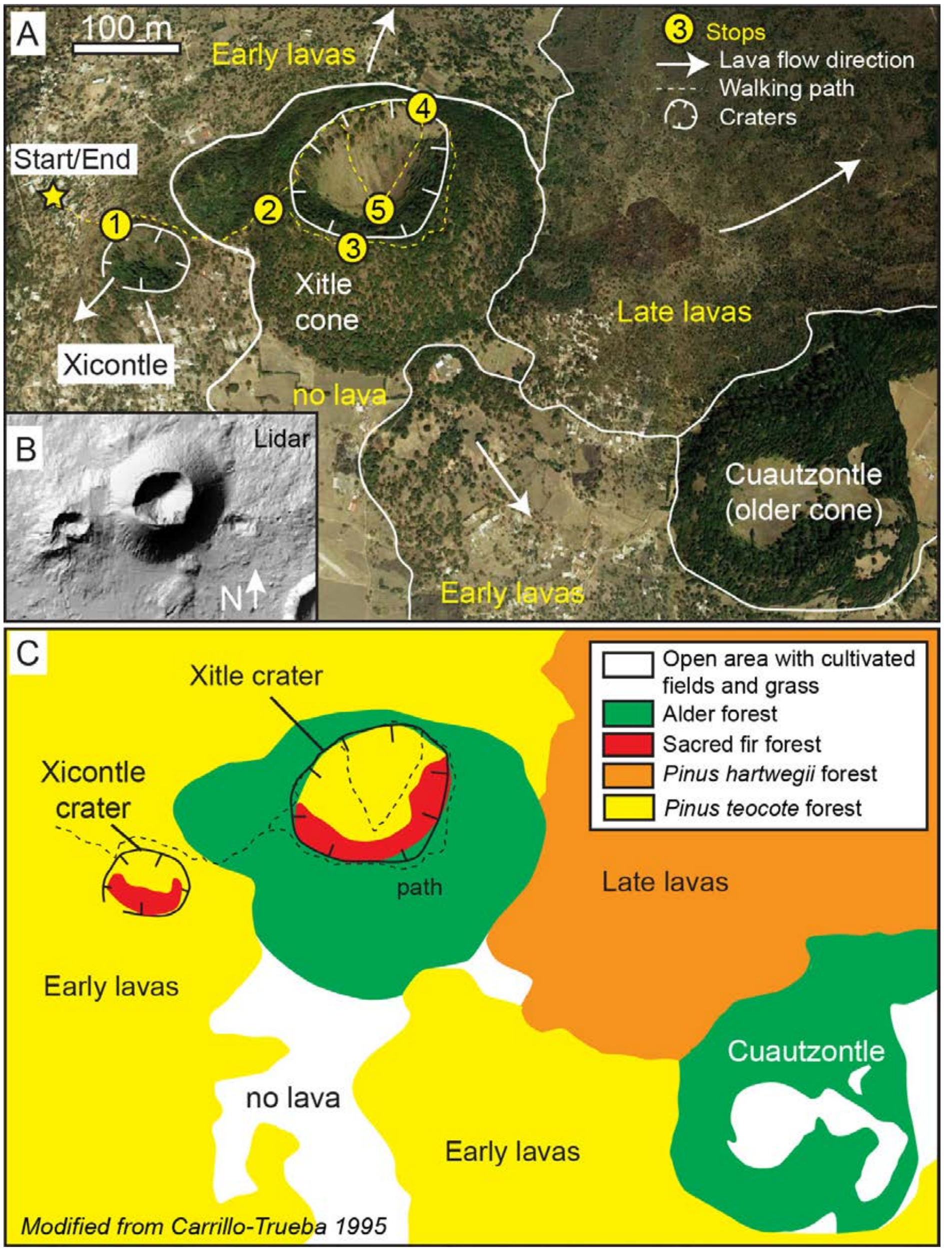

Figure 3: Maps of the Xitle cone geosite with the stops described in the text. A. Cartography of the main volcanic elements on a slightly-inclined view of satellite images draped over an elevation model from Google Earth. B. Shaded relief from a 5-m resolution digital elevation model that clearly shows the shape and inner crater of the main scoria cone and the Xicontle spatter-lava cone. C. Vegetation cover map modified from Carrillo-Trueba (1995) and drawn from satellite images and field observations. See the text for more explanation.

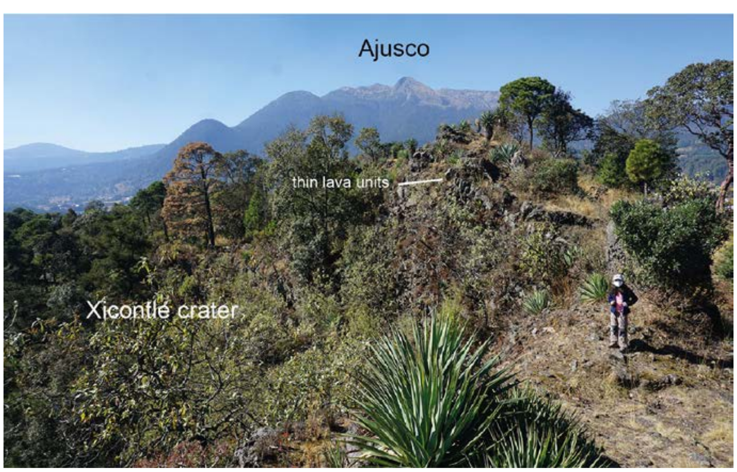

Figure 4: Stop 1. View of Xicontle crater and Ajusco stratovolcano in the background. Note the thin lava flows cropping out along the crater rim (top right), and the peculiar vegetation.

by oxidation (orange color). Soil is the result of the interaction of rock, air, water and biota and that is what we see here. This soil is considered very young because it has only been formed during a period of about 1670 years, which is the age of the parent material from which it is developing. Therefore, it is shallow and only presents a surficial mineral horizon of less than 17 cm thick (Ah1 and 2) in which an incipient accumulation of organic matter (h) is observed, which is the clearest pedogenetic process that can be identified by the dark color of the horizon (Figure 5A). This horizon A is above a Cw horizon of weathered tephra, different from the material found below (Figure 5A).

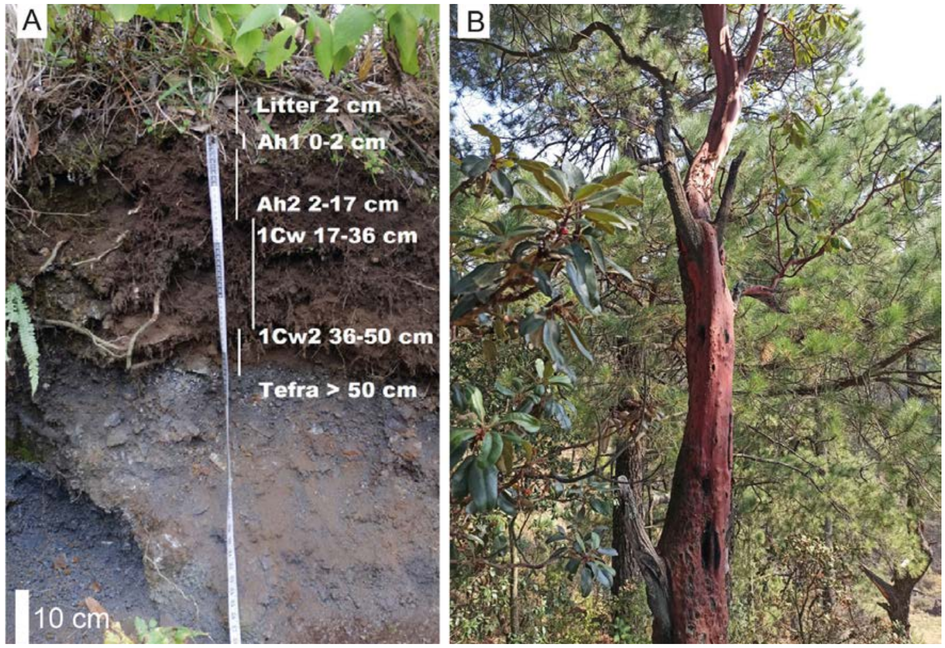

Figure 5: A. Stop 2. Photograph of soil and tephra section through the upper part of the Xitle cone, exposed along the walking path (see detailed description in text). B. An example of strawberry tree or madroño (*Arbutus xalapensis*) that is an abundant tree species in this area (photo taken by Perla Krauze).

Being such a young soil, there has not been sufficient time for the development of advanced pedogenetic processes, other than the accumulation of organic matter and therefore it is classified as a haplic Regosol, tephric, skeletic (humic), which means that it consists in a poorly developed soil with no special characteristics other than the accumulation of organic matter, with a large amount of stones. But, because the material on which the soil is developed is very porous, it allows root growth to depths of up to 70 cm, giving good support to the plants as seen in the size and height of the trees. This porosity also allows the infiltration of rainwater and its subsequent percolation to deeper layers. It can be said that this soil fulfills three important ecological functions: support for diverse vegetation, habitat for organisms and regulator of the hydrological cycle. The soils formed in volcanic environment are called andosols and have special characteristics that give them higher fertility.

The outer-slopes of the main cone that were mapped as an alder forest by Carrillo-Trueba (1995), present a wide diversity of trees that includes, in addition to alder (*Alnus firmifolia*), birch (*Betula pubescens*), pine trees (*Pinus teocote*), widespread strawberry trees or madroño (*Arbutus xalapensis*) (Figure 5B), oaks (*Quercus* spp.) and false agave (*Furcraea parmentieri*).

Stop 3: Xitle crater rim, southern side: Panoramic view (GPS: N19°14.708', W99°13.333', 3136 m asl).

After a walk of 20-30 mins., we get to the rim of Xitle crater on its highest point (*ca.* 3140 masl), near to a tower that is used by firemen to visually detect and monitor wildfires. The crater is deep (65-110 m, depending on the side) and steep (30°) (Figure 6A) which probably explains the name of Xitle that means "belly button" in the indigenous náhuatl language. This morphology reflects the young age of the cone whose original aspects have not been significantly affected by weathering. From this location the southern part of the Mexico basin can be seen and on clear days the view extends up to the Sierra de Guadalupe that marks the northernmost administrative limits of the city (Figure 6A). The ecological reserve (REPSA) can also be distinguished as a green spot in the entirely urbanized area. At this location, a small scarp exposes the well-bedded, loose coarse tephra layers with bombs that make up the upper part of the cone (Figure 6B). Nevertheless, below this, a lava outcrops and forms a vertical wall, which makes it dangerous to go down the crater slope at that location.

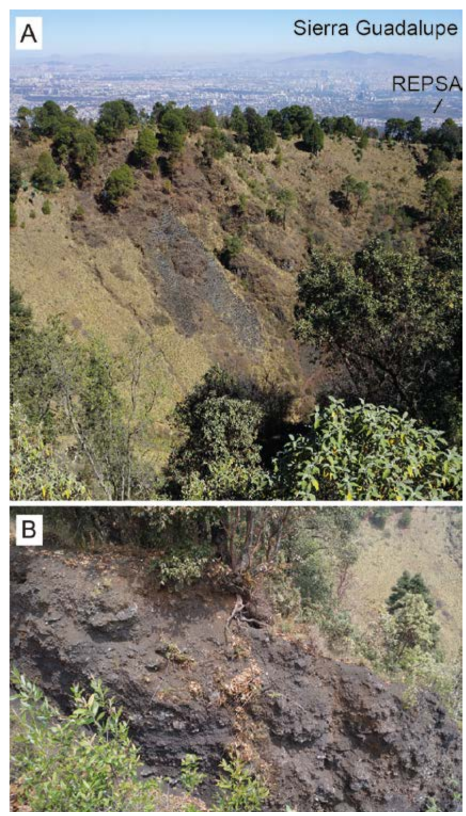

Figure 6. Stop 3. A. View from the southern part of the Xitle crater rim looking N, showing the deep crater and the southern part of Mexico City covered by smog. The mountain in the background is the Sierra Guadalupe. B. *Ca.* 2 m-thick exposure that shows lapilli to bomb tephra layers and is visible from a small scarp along the crater rim.

Stop 4: Xitle crater rim, northern side: Erosion and vegetation (GPS: N19°14.866', W99°13.233', 3091 m asl).

After following the eastern rim of the Xitle cone, we get to the northern point of the rim, which is the lowest (*ca.* 3090 m asl). From this point, looking towards the crater interior, note that the slopes are affected by gullies and small-scale landslides made of loose, bomb-size scoria, indicative of erosion by colluvial transport that controls the morphological evolution of the crater (Figure 7).

We can also observe the contrast between the inner slopes of the crater. The N-facing slopes are covered by a fir forest (*Abies religiosa*, locally named abeto or oyamel) whereas the S-facing slopes are dominated by grass and small shrubs (*Muhlembergia macroura*, *Arctostaphylos pungens* and *Festuca tolucensis*) (Figure 7). Associated and conspicuous native vegetation in the area include thistle (*Cirsium ehrenbergii*), tepozán (*Buddleja cordata*), boneset (*Ageratina glabrata*) and maguey (*Agave salmiana*). All these plants are important hosts for pollinators such as bats, nocturnal butterflies, hummingbirds, bees, wasps and beetles. Furthermore, the different plant species live in symbiosis with different types of mycorrhizal fungi that are extremely important for biogeochemical cycles and to maintain healthy soils, fulfilling many ecological functions such as carbon sequestration, nutrient translocation, soil stabilization and infiltration facilitator.

At the GPS location **N19°14.882', W99°13.258', 3096 m asl**, we follow a 1 to 2-m-deep gully to go down the inner part of the crater. The gully exposes sequences of ash and lapilli-rich layers. At about halfway downslope, the terrain turns notably coarser with an abundance of loose, cm-size bombs with mostly black to red colors, some with a white to yellowish coating. This accumulation of loose blocks and bombs is probably the product of a small landslide that remobilized partly-consolidated colluvium that coats the crater interior.

Visitors who do not wish to go down the crater (note the steepness and unsteadiness of the terrain) can continue by the path along the crater rim.

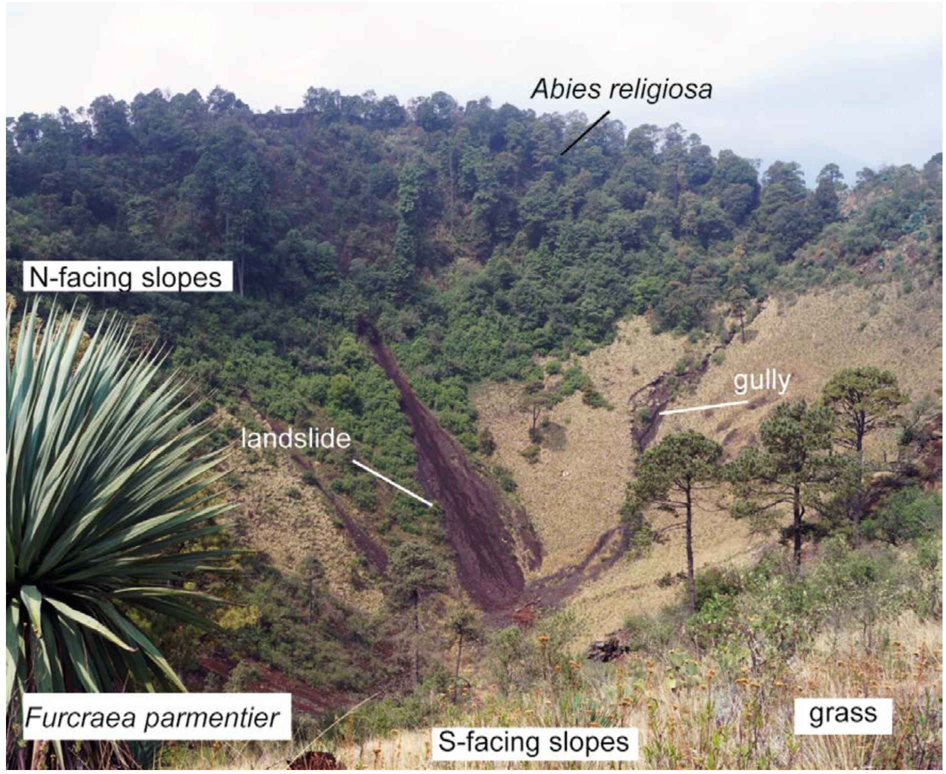

Figure 7. Stop 4. Photograph taken from the northern part of the crater rim, looking south, showing the N- and S-facing crater slopes and their contrast in vegetation and erosional pattern.

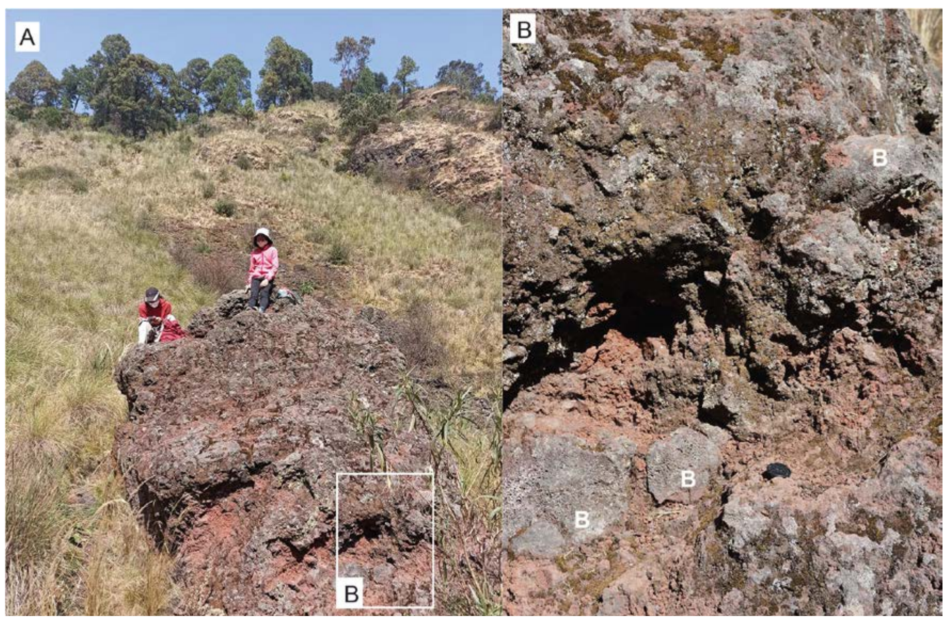

Figure 8. Stop 5. Agglutinates at the bottom the Xitle cone crater. A. General view of an agglutinate pile forming a large block. Rectangle shows location of Figure 8B. B. Close view of the agglutinate pile showing the abundance of subrounded vesicular bombs (B on the picture).

Stop 5: Crater bottom, agglutinates and bombs (GPS: N19°14.797', W99°13.318', 3026 m asl).

At less than thirty minutes after the previous stop, the bottom of the crater is reached. At this site, it is interesting to note the wide range in color (black, red to yellow and white) displayed by the bombs that cover the floor and part of the inner walls of the crater. This coloration is often attributed to processes of oxidation and circulation of gases in the rocks as they accumulated, still hot, on the ground. Nevertheless, we have found evidence for the development of tiny organisms on these blocks that contribute to their coloration and are proof of the rapid development of life in volcanic settings.

At the bottom of the crater and on its interior sides, there are also 3- to 4-m-high red piles of agglutinates that contain large bombs which are strongly welded (Figure 8). Those formed during weakly-explosive activity inside the crater. Due to the low explosivity, the magma was emitted

Figure 9. A. Picture of path following gully on the western side of the Xitle crater.
B. Exposure along the gully of well-sorted layers of lapilli-size fragments. Note the larger fragments on the surface.

Figure 10. Location of main anthropic, archaeological and volcanic elements on a slightly-inclined view of satellite images draped over an elevation model from Google Earth. The red lines indicate cuts in the lavas that were made during early archaeological excavations (in park) and the construction of the paper factory (now shopping center).

as large lumps that accumulated still hot on the crater sides, forming piles of red spatter. Saxicola crust has grown on these blocks since the eruption and can be easily observed on the near-vertical walls using hand lenses.

From Stop 5 to end: We follow a steep gully to exit the cone crater to the west (Figure 9A). Along the path, sections through inward-dipping layers of slightly-rounded lapilli-size ash can be seen (Figure 9B), which are the results of small avalanches of loose deposits, that probably occurred after the eruption. Their high grade of sorting can be attributed to a process of classification of the grains by size occurring during the avalanching. These deposits are covered by a thin, light-color fine-grained soil due to low organic material accumulation, great sun exposure, low humidity and poorly-developed vegetation made of grass and few trees.

After reaching the path going around cone rim, we follow it to the S and then take a path to the right, at a gully that exposes a thick soil (GPS: N19º14.772', W99º13.420', 3112 m asl). Afterwards, we follow the path down the western side of the cone and then down a gully to the left to get back to the same path followed earlier (see map on Figure 3). The parking lot is reached after about 20 mins.

Day 2: Morning: Cuicuilco archaeological site

This site encloses an archeological and ecological park that is located at the crossing of two main avenues (Periférico Sur and Insurgentes Sur) of the SW of Mexico City and several large shopping centers, and hence represents a natural green island in a dense urban area with heavy traffic and a constant flow of goods and people (Figure 10). The park stands out by its round pyramid that was surrounded and partly covered by the Xitle lavas, which superbly and very clearly illustrates the great impact of an eruption of a small magnitude on a human settlement at the beginning of our era (Gónzalez *et al*., 2000; Lugo Hubp *et al*., 2001; Pastrana 2018). Despite its significance, the Cuicuilco site remains poorly studied and is also scarcely visited.

Itinerary and description of stops:

The excursion starts at the entrance of the park, at about 15 min drive from the UNAM campus (Figure 2). The entire excursion (stops shown on Figure 10) takes about 2 hours, including the time for stops for discussions.

Stop 1: Lava flow field (GPS: N19°18.089', W99°11.030', 2294 m asl).

The main entry path in the site leads to the pyramid and crosses a patch of the hummocky lava field with typical pahoehoe landforms, along with flora and fauna that typically occur in this distal part of the flow-field. After 150 meters a transversal cut across a sheet lobe can be observed, which exposes the vesicular interior of the lavas (Figure 11A). From this location looking to the SW, the Xitle cone can be observed in the far distance and, further away, the Ajusco stratovolcano (Figure 11B).

Stop 2: Cuicuilco main pyramid (GPS: N19°18.096', W99°10.899', 2301 m asl)

The path leads to the pyramid whose contact with the surrounding lava was exposed along its eastern and southern sides by excavations. The first excavations were undergone between 1922 and 1925. Prior to this, the upper part of the pyramid cropped out between the lava surface (Cummings 1926; Pastrana 2018).

Figure 11. A. On the foreground, *ca*. 2 m deep cut across a sheet lobe that displays the characteristic vesicular upper crust and dense core of pahoehoe lavas. Note the typical native vegetation (palo loco, nopal) and some exotic trees (e.g., pirul). B. View of the Xitle and Ajusco volcanoes to the SW. Note that all the pictures were taken in the rainy season and hence the vegetation presents a green foliage. In the dry season (November-May), the vegetation is decreased and present mostly a dry and brown foliage, so that the lava is better exposed.

Figure 12: A. View of the round pyramid. Note the contrast with the tall building to the left that was recently built along Periferico Sur, Mexico City´s busy ring road that borders the site. B. Stop 2. View from the top platform of the pyramid towards the SW, where the limits of the Mexico Basin can be seen in the background (Sierra de Las Cruces).

The pyramid forms a temple with a conical truncated base, about 110 m in diameter and 20 m in height (Kelly, 1982; Figure 12A). It is one of the few existing rounded pyramids in Mexico and is, with the exception of small mounds nearby, the only remaining building of Cuicuilco (Cummings, 1926). After observing the pyramid from its base, we climb on its top to better observe the surroundings from there and be able to discuss the volcanic, tectonic and topographical context. The top platform of the pyramid provides clear views over the SW corner of the Mexico basin and the northern slopes of the Sierra Chichinautzin (Figure 12B). On clear days (a rare occurrence), the Teuthli cone and the Popocatepetl stratovolcano can be seen to the southeast. Note that other smaller pyramids have been found nearby, at Peña Pobre and Tenantongo located 500 m and 1 km to the SW, respectively.

Early studies postulated that this site was that of a large city inhabited by 20,000 people. According to this interpretation, the Xitle eruption would have triggered the sudden migration of this large population to the northern part of the Mexico basin where they would have founded the city of Teotihuacan (110 AC-650 DC), which was one of the largest of its time worldwide (Heizer and Bennyhoff, 1958; Sanders *et al*., 1979; Parsons, 1989). This appealing narrative remains in the pictorial representations of Cuicuilco exposed for example in the *museo de sitio* (Stop 5). Nevertheless, recent works picture it as a mostly agricultural area with a well-developed system of "chinampas" or canals and few constructions (Pastrana, 2018). There is still considerable debate over whether the eruption directly caused the abandonment of Cuicuilco and the migration of its population to Teotihuacan or if both events are not connected.

Stop 3: Stratigraphy (GPS: N19°18.088', W99°10.862', 2287 m asl)

Afterwards, we walk down by the eastern side of the pyramid to visit a tunnel excavated below the lavas where the lava base can be observed along with the underlying ash and paleosol (Figure 13).

A tunnel excavated below the lava exposes from top to bottom: the billowy base of the lava that is proof of its emplacement as inflating pahoehoe lobes, a thin reworked dark ash layer produced by early explosive activity at the cone, and a buried soil (paleosol) that is locally indurated and transformed into red brick due to the lava heat (Figure 13). This paleosol preserves important information on the paleoclimate and human occupation at the time of the eruption (Solleiro-Rebolledo *et al*., 2016). The ash below the lava is locally finely stratified, indicative of an intense pulsating activity with strong explosions. The basal ash layer contains bits of charcoal which were likely produced by the burning of vegetation along the advancing lava flow front (Siebe, 2000). We can see in the tunnels and cuts that the lava base molds the steps of a ramp that was leading to the top of the pyramid. Most of this ramp was extracted by mistake during early archaeological investigations but part of it can be seen at the exit of the tunnel to the E (Pastrana, 2018).

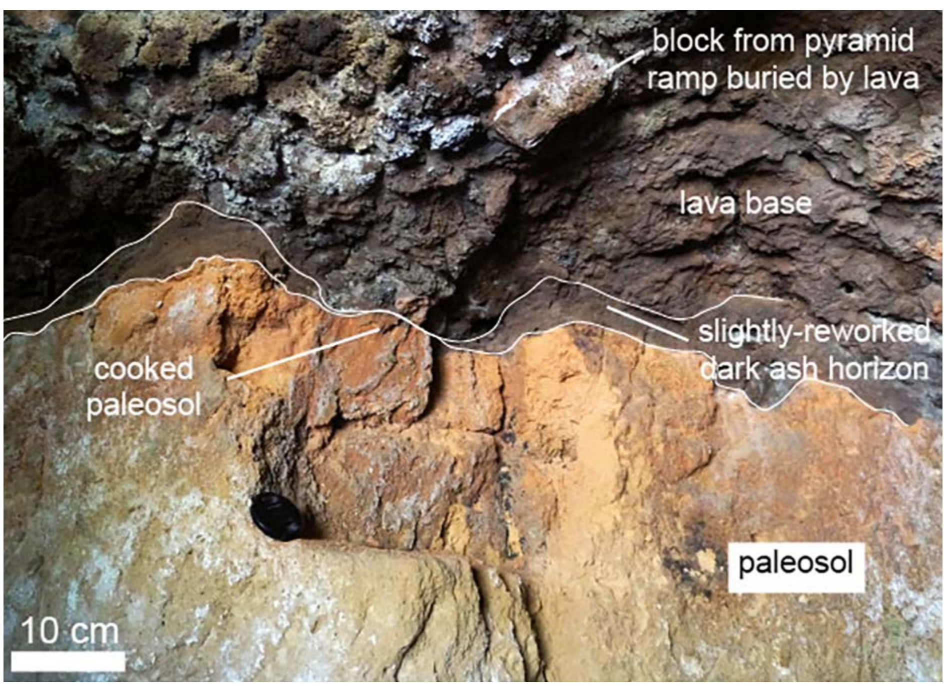

Figure 13: Stop 3. Photograph taken inside the tunnel excavated below the lavas that shows the paleosol, ash layer deposited by an early explosive phase at Xitle volcano and lava base. Some rectangular sub-rounded blocks stuck on the lava base represent parts of the ramps of the pyramid which were buried by the lava. The loose material of the ramp underneath was extracted during the excavation because it was believed, wrongly, to be formed by debris.

Stop 4: The mysterious stele (GPS: N19°18.066', W99°10.890', 2287 m asl)

We will follow the excavation between the lava and the pyramid, to reach a location where a 4-m-high carved stone was found, buried in sediments. This impressive stone, whose origin remains unknown, was apparently buried during the enlargement of the pyramid at pre-hispanic times. It consists of a vesicular, crystalline rock considered as andesite.

Stop 5: Museum (GPS: N19°18.047', W99°10.900', 2291 m asl)

Next, we will visit a small museum (*museo de sitio*) created in 1948 that presents basic information about the setting of the site and archaeological findings. There is also a painting representing, in an artistic way, the destruction of the pyramid during the Xitle eruption.

Stop 6: Pillow lavas (GPS: N19°17.937', W99°10.931', 2289 m asl)

Finally, we will go to observe an outcrop located along a carpark in the nearby commercial center of Plaza Cuicuilco, which was originally a paper factory (*Fabrica de Peña Pobre*; Figure 14). The abundance of eucalyptus in the whole area is a consequence of the development of this industry. At this location, archaeological excavations revealed rounded, pillow-like lava forms embedded in clay-rich sediments (mud) and covering layers of rounded clasts (Figure 15). Pillow lavas are the typical form of lava emplaced in water, where the outer lava crust solidifies very quickly (quenching), giving it its peculiar globular shape. The finding of these lava types here confirms other inferences that Cuicuilco was located in a deltaic plain, at the convergence of river streams that flowed down the slopes of Ajusco (e.g., Córdova *et al.*, 1994; Lugo Hubp *et al.*, 2001). A more recent interpretation is that the lavas were emplaced into a large channel ("canal maestro") that fed water to large areas of the agricultural fields of Cuicuilco (Pastrana, 2018). A 1929 map of the area reports a river (*Río de Tlalpan*) bordering the lava front in this area.

Near to the outcrop of pillow lavas, a section across a thicker lava unit reveals a structure that is common in these lavas and were called *tubos de explosión* (Waitz and Wittich, 1910) because they were believed to be associated to lava-water explosive interaction. Nevertheless, there is no pyroclastic material and these structures were named lava-wedges and re-interpreted as sutures between two sheet lobes emplaced side by side (Walker, 2009).

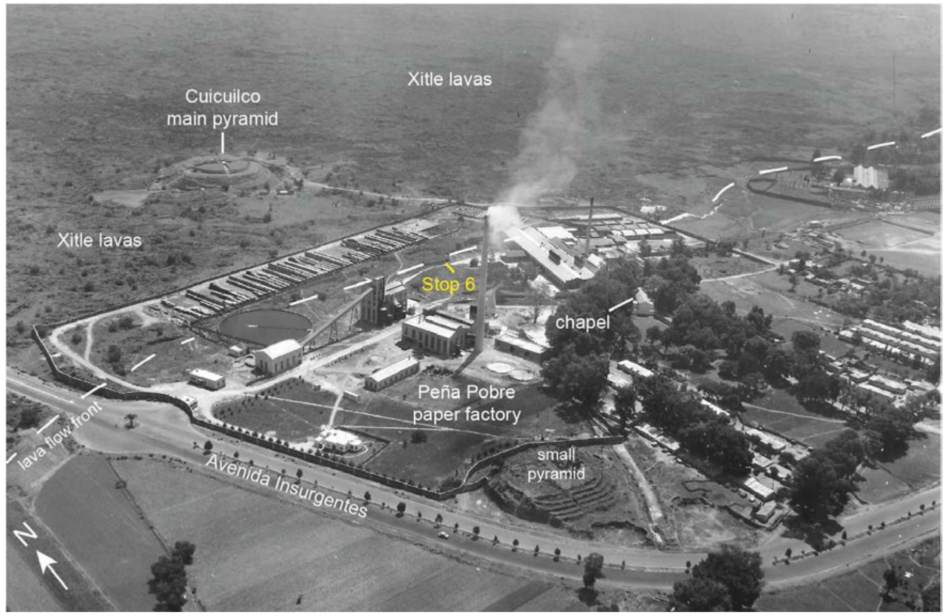

Figure 14: Aerial photo view of the main pyramid of Cuicuilco and the Peña Pobre paper factory, which was established in 1845 and closed in 1986 (after 141 years) due to the contamination to be converted into Plaza Cuicuilco, a commercial center. The approximate location of the lava front is shown (the general direction of flow is from left to right on the picture). Location of site visited (pillow lavas) is marked, as well as other reference points. The two tall chimneys of the factory were kept and are still visible in the plaza. Some of the machinery was also conserved and can be seen inside the commercial center, however without any indication about their origin or original function. Note the existence of another smaller pyramid in the bend of Avenida Insurgentes that is officially named "Montículo de Peña Pobre". Aerial photo taken in 1944, courtesy of Alberto Lenz.

Day 3 - Afternoon: Cantera oriente, REPSA

The "Cantera Oriente" (eastern quarry in Spanish) is located at the eastern border of the UNAM campus (Figure 16). Despite its location near one of the busiest metro stations of the capital (Universidad station), this place is a very quiet green area that was restored with exotic plant species and contains a water body divided by dams or barriers built to hold back the water. This site is known informally as the "Cantera de los Pumas" because it encloses the training grounds of the infamous "Pumas" UNAM football team, and visits are allowed only by appointment either through the ecological reserve (REPSA) or the persons in charge of the "Pumas" sector.

Itinerary and description of stops:

The excursion starts at the NW entrance of the park (Figure 16), at 5 min walk from the Metro station. The entire excursion (stops shown on Figure 16) takes about 2 hours, considering the stops for discussions.

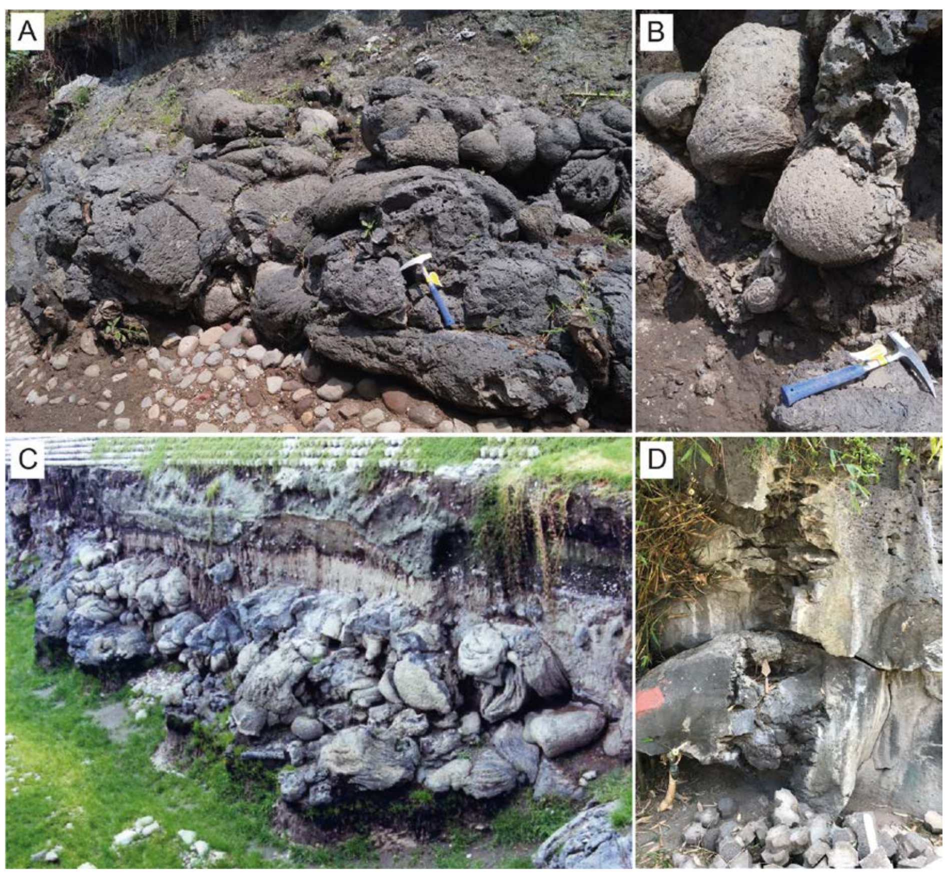

Figure 15: Stop 6. Rounded pillow-type lavas exposed along the ground level of a carpark in the commercial center. A. and B. Pictures taken in late 2018 when archeologists obtained permission to study this area in detail because of the imminent occurrence of major building works. This outcrop is mostly overgrown with vegetation at the moment. C. Picture of the same site taken in 1997. This outcrop was interpreted as equally-spaced lava flows which were emplaced into channels that are parallel and transversal to a central agricultural channel, corresponding to the Mesoamerican system of the "Chinampas". INAH 1997. D. Exposure of a structure in the lava which was initially thought to be produced by lava-water interaction, but which was re-interpreted as a suture between two adjacent inflated sheet lobes.

Stop 1: History of the quarry (GPS: N19°19.225', W99°10.417', 2258 m asl)

Prior to begin the tour, it is useful to learn the history of the site and to know that the quarry originated from the intense exploitation of basaltic material for 24 years (1970-1994; Figure 17). It is estimated that approximately 5.5 million m³ of material was extracted from a 14 ha area (Lot, 2007) because of a concession that the UNAM gave to the concrete plant for its utilization in road works

In 1985, after the great earthquake of September 19, the city's government used the site to dispose of debris from the destroyed buildings, until the University authorities stopped these activities, designating 7.4 ha of the quarry as part of the ecological reserve (REPSA) in 1996 and the remaining area (aprox. 7 ha) for the construction of the installations of the Pumas Club, thus ending the speculation of using the land as a sanitary landfill and its subsequent use for the construction of a housing unit.

In 1997, the ecological rehabilitation project began by removing the rubble to form terraces, make a road and apply layers of soil and manure to form an artificial soil (technosoil) in which shrubs, trees and other mostly exotic plants were planted (Stop 2; Figure 18).

Stop 2: Terraces and site management (GPS: N19°19.213', W99°10.375', 2276 m asl)

After this brief introduction, we walk down the slope where the terraces are located and where we can observe how the site is managed and what are the characteristics of the technosols.

The soils present on the terraces are called technosols because they were made artificially from gravel, sediments and manure. They have poor quality to fill their function as vegetation support due to

Figure 16. Cantera Oriente site. This site is separated to the main UNAM Campus (to the left) by the Avenida Delfin Madrigal and is partly managed by the REPSA (broken white line on image). Note that the entire area is constructed over the Xitle lavas but those only outcrop extensively in the REPSA. In the popular Santo Doming neighborhood, there are only small vertical outcrop along roads and probably some small remaining outcrops in private gardens.

Figure 17. View of the quarry after mining. The basalt was mined down to the level of the former soil (in brown in the foreground). Photo taken from the S part of the quarry in 1994, before starting the ecological rehabilitation process. Note that in the N part of the quarry in the background of this picture, vegetation growth had already started in the part where water from the shallow aquifer that was drilled was running out. Courtesy of Francisco Martínez.

limiting characteristics, including their low porosity and low organic matter content, high bulk density and a massive structure, all of which are reflected in low moisture retention and aeration capacity, poor rooting condition and low nutrient content. For many years it has received the typical management for the care of gardens with lawn and the fallen leaves were swept away from the soil surface, which prevented the incorporation of organic matter.

Stop 3: Water springs and lake

Coming down the talus, we will stop at the base of the western quarry wall, where two closely-spaced small water springs can be observed (Figure 20A). Then, we will observe the lake walking over the artificial dam towards the east wall of the quarry (Figure 20B).

This water spring is part of a series that emerge from fractured areas near the base of the lava pile at several locations and feed superficial water bodies that covers 12,000 m² and promote the development of a vast swampy land (aprox. 20,000 m²) (Lot, 2007). The fractures in the rock are typical for young basaltic lavas, such as those of Xitle, which have high hydraulic connectivity and permeability, which means that water infiltrates quickly and percolates in the porous rock, forming aquifers (Peterson, 1972).

Figure 18. A. Movement of the material deposited in the quarry to stabilize the slope forming terraces for subsequent revegetation and outlining the access road that was built afterwards. Courtesy of Francisco Martínez, 1997. B. Exotic trees which were planted on the terraces. Courtesy of Manuel Figueroa Maheng, 2006.

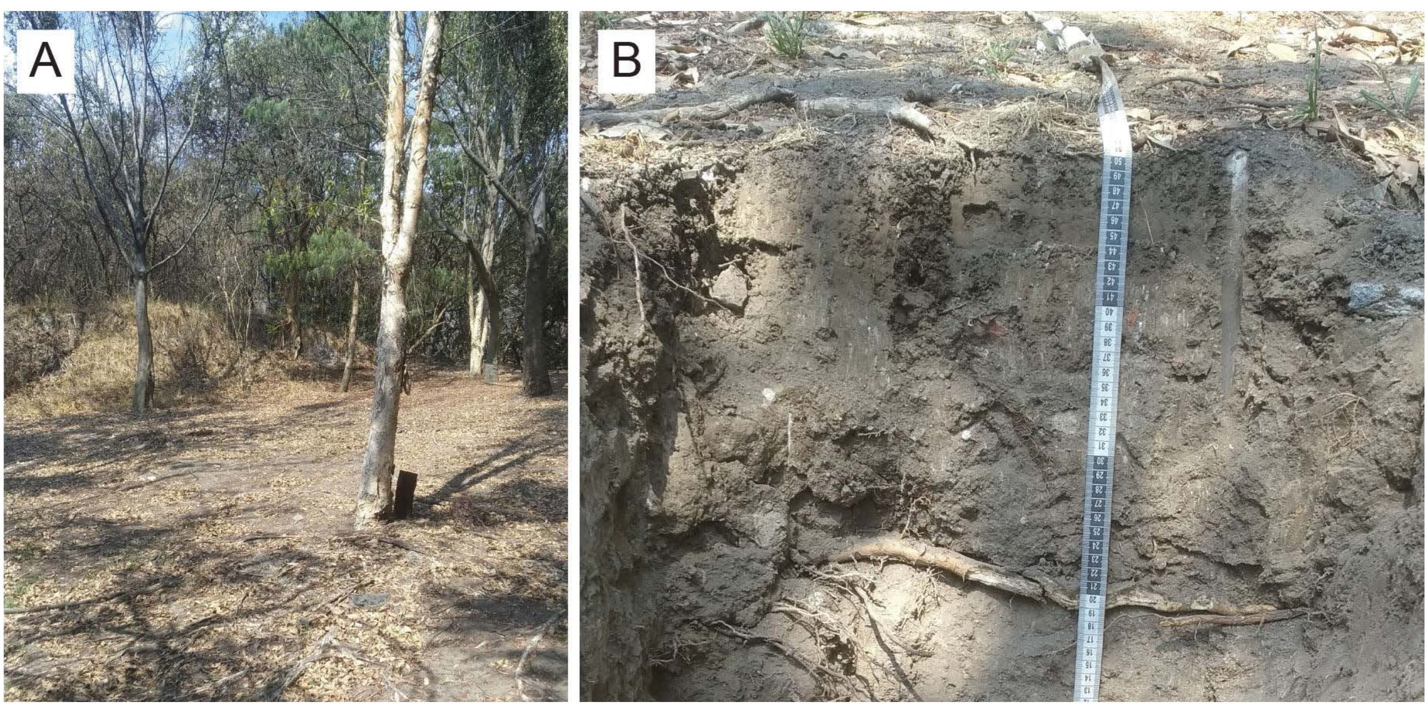

Figure 19: A. Photograph of the terrace. This photo shows the result of the soil management (continuous leaf litter sweeping) that has left the soil without a leaf cover, which prevents the accumulation of organic matter in the soil and makes it prone to erosion of the particles, exposing the surface roots of the trees. B. The soils present on the terraces are developed from materials made or transported by humans. They have poor quality (see text). Pictures taken by Silke Cram in March 2020.

For their specific topographic setting, the Xitle lavas act as a natural conductor of rainwater from more humid, higher parts of the Sierra Chichinautzin (the Xitle vent area visited the previous day), to the drier, lower-elevation basin (where the Cuicuilco and the UNAM campus are located). They also serve as a buffer to floods that occur every summer rainy season in the basin, because the lavas soak up water. Despite the shortage of water resources in the basin and common interference of construction works in them, the aquifer in the Xitle lava has been poorly studied and is strongly impacted by anthropic pollution (Canteiro *et al.*, 2019). Its existence should be valued and recognized as a means to increase the city's sustainability.

The small lake in the quarry is surrounded by a green area managed by the REPSA that has some interest in biology and ecology (Lot, 2007). Environmental and ecological aspects of the quarry are significantly distinct to other parts of the ecological reserve, motivating their management as a separate entity, and the publication of a dedicated field guide by Lot (2007). The specificity of the area and its main interest is the lacustrine environment that is now rare in the Mexico Basin but was common in the past, prior to drainage of the paleolakes. In that respect, this area may be considered as a snapshot of the pre-urban environment in the Mexico Basin. Rather unexpectedly given the high degree of transformation of the area and introduction of exotic species, the small lakes contain a rich aquatic fauna and flora with many native and endemic species of restricted distribution, and some even relict or rare elements with respect to their presence in the Mexico Basin (Lot, 2007). The isolation of this area that is surrounded by an up to 40 m wall of lava and which access is restricted, makes it an ideal laboratory for research investigations, and gives it high landscape and aesthetic values.

Stop 4: Vertical exposures through the lavas (GPS: N19°19.071', W99°10.348', 2264 m asl).

The Xitle lava is probably the most excavated young basaltic lava in the world, due to the growth of one of the largest cities in the world, first near its margins and then directly on it.

Excavations have taken different forms with time. Large quarries made to extract building stones were most prominent prior to the urbanization of the area. Important road cuts were made when large avenues (Insurgentes Sur, Periferico Sur) were constructed. Now, excavations are restricted to building areas that are smaller and private, such as underground parking areas or the anchor of building structures to make them resistant to earthquakes. However, in most of these excavations, any resulting exposures of the internal structure of the lava are ephemeral because they are covered up when the works end, which hamper that they could be used for research or education.

Early-on, the outcrops resulting from the extraction of rocks in quarries have involuntarily motivated pioneering research works such as those of Waitz and Wittich (1910), Wittich (1919), Schmitter (1953), and Badilla-Cruz (1977), but also the more recent works of George Walker, one of the makers of modern volcanology, who revisited these works and re-interpreted various previous observations (Walker 1993, 2009). The many sections cut through the lavas have also permitted diverse studies on the internal magnetic properties of basaltic lava flows (e.g., Cañón-Tapia *et al.*, 1995, 1996). The quarries represent an opportunity to promote the preservation of geoheritage, if they are accessible and preserved.

The "Cantera Oriente" is the largest remaining quarry in the Xitle lava which has not been urbanized and where the lava can be easily observed and accessed for sampling, which is of considerable interest for scientific studies. In that respect, the "Cantera Oriente" is the loca-

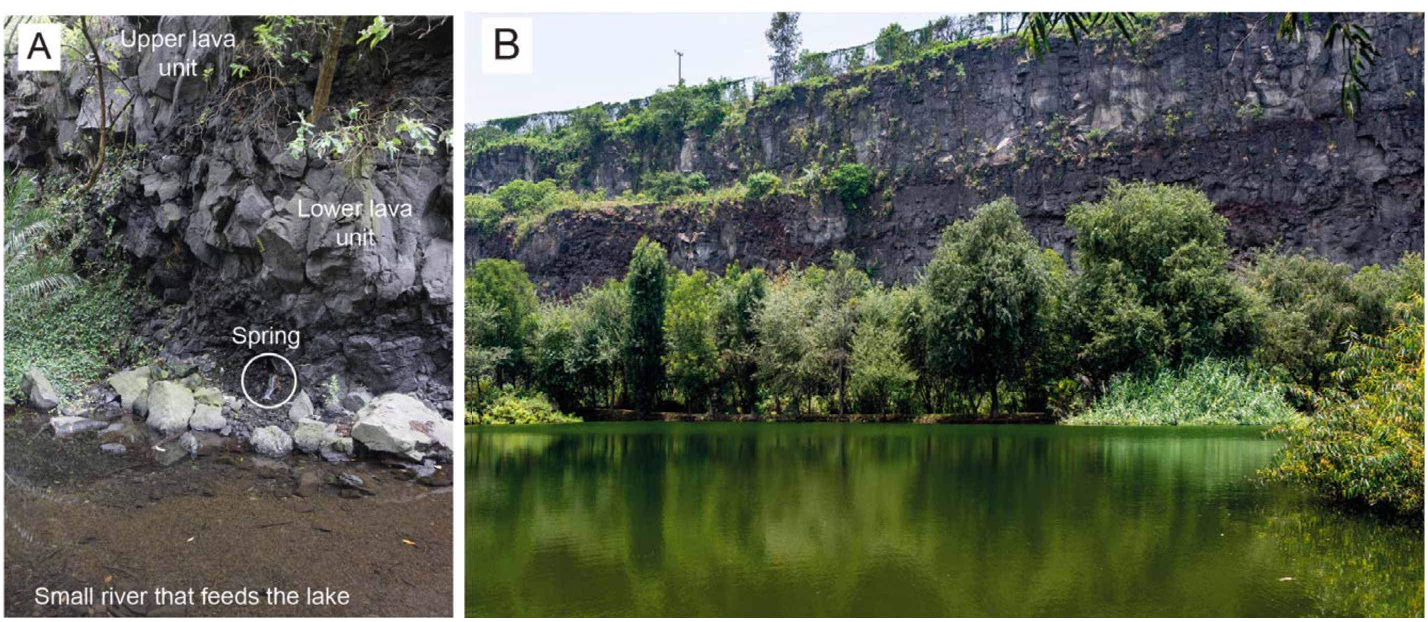

Figure 20: A. Stop 3. Photograph of a water spring that can be seen along a walking path at the base of the highest quarry wall along the western border of the site. Note the two distinct lava unit. The lower unit seems to have hacking jointing (irregular, closely spaced vertical fractures), which may indicate that the lava interacted with water during its emplacement, as this increases the cooling rates and affect the columnar pattern (Long and Wood 1986). B. Photograph of the lake and the eastern quarry walls with distinct lava units.

tion where, to our knowledge, the thickest pile of young basaltic lava fed by a single eruption has been found in Mexico. The artificial cuts of the quarry walls display spectacular exposures across an up to 40 m-thick pile of inflated pahoehoe lava flows (sheet lobes and tumuli). These are continuous over a lateral distance of 900 meters and consist of five main vertical units (Figure 21A). The high total thickness of the lava and its complex internal structure points to years of slowly advancing lobes, progressively filling a large depression (Guilbaud and Siebe, 2009).

This site is important for interpreting the mode of growth of the lavas by the inflation process (or swelling) that creates the specific internal structure of the lava (vesiculated crust at the base and top, dense core: Figure 21B) and the formation of the sheet lobes and tumuli that have planar and uplifted geometries, respectively. These features that are exceptionally well displayed by the quarry walls, are typical of pahoehoe lavas observed in a wide range of settings and diagnostic of long-lived, far-reaching lava flows (Self *et al*., 1998).

Specifically, at Stop 4, the cut through the lavas is well exposed and can be observed closely (Figure 21B).

Figure 21: Stop 4. A. Photograph of the vertical cut through the lavas from the artificial dam. Note the complex internal structure. B. Photograph of the wall from its base on the artificial dam, where the interior of a lower lava unit can be seen, overlaid by an upper one. Note the red contact between the two units that is related to the oxidation of the upper crust of the lower one, maybe due to gas escape.

Day 3 - Remaining lava outcrops ("pedregales") in UNAM campus

The REPSA is the largest remaining area where the distal part of the Xitle lava flow field and its related ecosystem can be observed. The morphology of the lava in this area is typical of the pahoehoe type that is common in Hawaii but also in other basaltic lava fields (Self *et al*., 1998). Because of the need to conserve and preserve this last relict of the original ecosystem and the multiple threats, the core part of the reserve is closed to visits, but the campus encloses a total of 48 ha of "pedregales remanentes" that are remaining patches of the lava field not destroyed by infrastructure and not covered by a thick layer of construction material waste forming anthropogenic Technosols (Figure 22A; SEREPSA, 2008).

In the past two decades there have been some initiatives to rescue these "pedregales", restore their ecological system and use them for outdoor teaching ("aula viva"). They are also great places to develop research projects, in particular involving local students.

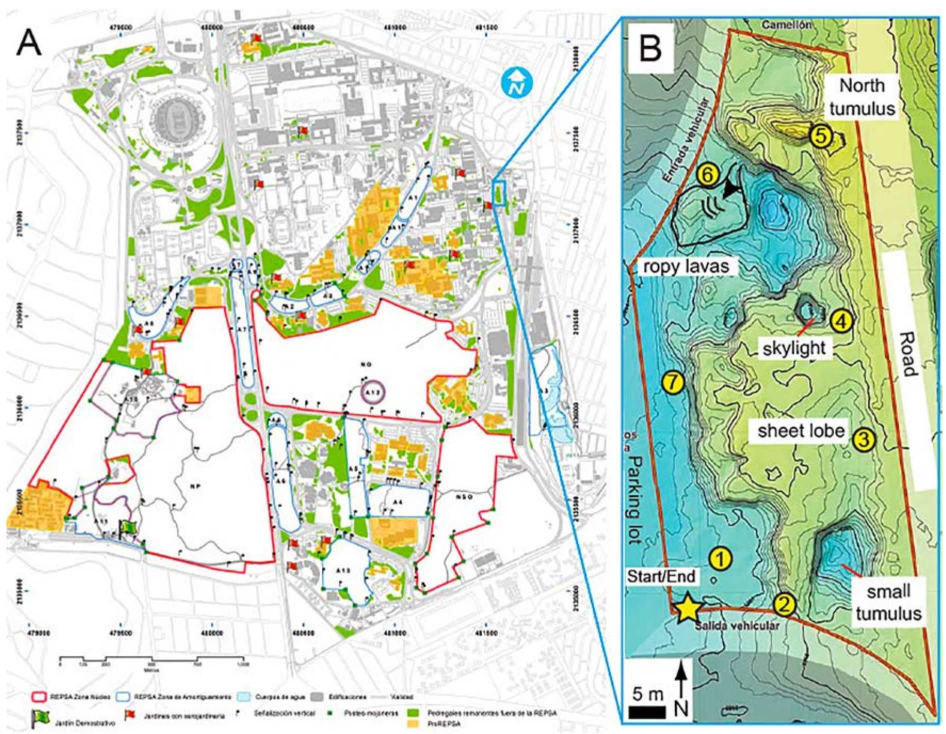

Figure 22. A. Location of the Geopedregal site within the University City campus. Atlas map of the reserve by Lot *et al*., (2012). Surrounded by a red line are the areas protected by the REPSA. Filled in green are the "pedregales remanentes" that are remaining lava outcrops not protected by the REPSA but that provide multiple ecosystem services. B. Stops within the Geopedregal site, on a topographical map. Its location on the A map is shown.

In this excursion we will visit an area where we have developed such initiatives, in a collaborative project between three scientific institutes: the institutes of Geophysics, Geology and Geography. The Geopedregal site is the most consolidated site, after 10 years of restoration whereas the others are in process to be included in a general management plan.

Figure 23. Stop 1. Project Geopedregal. Pictures of the initial state of the site which was used to dump solid waste of all types and where homeless people were living.

GEOPEDREGAL SITE

During the excursion we will follow a path that surrounds the site, making stops at key locations (Figure 22B). This excursion lasts approximately 1 hour including explanations at the distinct stops.

Stop 1: Entrance of the site and presentation of the project (GPS: N19°19.680', W99°10.536', 2270 m asl)

The Geopedregal site was created in 2012 on a *ca.* 3000 m² lava outcrop located on land shared by the institutes of Geology and Geography. The site, originally used as a dump (Figure 23), was cleaned, restored and converted into a small geosite.

This site exposes in a preserved environment the main aspects of the lava morphology and related biological adaptations, ecosystem services such as thermal regulation, capture by infiltration, pollution buffering and pollinator corridor of native pollinators as bats, hummingbirds, bumble bees, butterflies. The main lava structures consist of an elongated, planar sheet lobe with steep lateral margins and an oval dome-shape tumulus with axial and lateral clefts, that are separated by a depression (lava rise pit). Detailed descriptions of these types of lava structures in the Kilauea volcano (Hawaii) can be found in Walker (1991) and Hon *et al.* (1994).

The site is used to conduct several research programs, field work, and science education for school and university students of different levels. It is also used for photographic expositions and guided visits (Naturalist), as well as local festivities that draw people from the nearby research centers to the site and help to secure the existence of this site. It is the first "pedregal remanente" of the University campus with a complete program of restoration that is protected by the University laws (Zambrano *et al.*, 2019).

Stop 2: S sheet lobe and small tumulus, native vegetation (GPS: N19°19.674', W99°10.530', 2270 m asl).

The southern part of the Geopedregal site is made of a sheet lobe ("lava rise" or "lava plateau") that is bordered by a steep margin that consists of uplifted, vertical slabs of ropy lava separated by deep cracks (inflation clefts) (Figures 24A and 24B). The eastern margin of this lobe overlaps a low tumulus structure which was unearthed during the cleaning of the site (Figure 24C). This tumulus is probably part of an underlying lava unit that was emplaced prior to the emplacement of the main sheet lobe. Thanks to local deep excavations such as at the eastern quarry (previous site), we know that the lava pile can be thick and consists of multiple units.

In this small area with irregular morphology and high geodiversity, we can already see the diversity in associated vegetation (Figure 24B). Depending on the microhabitats with differential temperature, humidity and light conditions, diverse plant species and community consortia can develop. It is noteworthy that only some of the species were introduced, the others developed naturally. They range from cryptobiotic saxicola crust (crust made by organism growing directly on the rock) formed by an association of cyanobacteria, lichens, and bryophytes, to scrub vegetation dominated by the local native plant called "palo loco" (*Phytocaoulon praecox*) that gives its name to the vegetation type: xeric scrub of Phytocaoulon, named before Senecio (*senecioetum*).

Community structure is made by agaves and several terrestrial orchids (*Dichromanthus* spp., *Bletia* spp., etc.), with few tree species ("tepozán": *Buddleja cordata*, reintroduced "encino": *Quercus rugosa* and "copal": *Bursera fagaroides* and *Bursera cuneata*) that grow mostly in deep fractures in the lava such as inflation clefts and skylights (see Stop 4).

Conspicous scrub species are "orejas de burro" (*Crassulasean Echeveria gibbiflora*) that typically grows in fractures and shallow cracks. Cactus ("nopal": *Opuntia tomentosa*, *Mammillaria magnimamma* and the endemic *Mammillaria haageana san-angelensis* that is considered extinct in the REPSA and was reintroduced in the Geopedregal by clones) and the bat-pollinated agave (*Manfreda brachystachya*) that grow on flat surfaces exposed to abundant sunlight.

Stop 3: Natural versus artificial soils (GPS: N19°19.687', W99°10.525', 2270 m asl).

At this location, we go down into a small depression that is located between the pedregal and the perimetric path (Figure 25A). On

Figure 24. Stop 2. A. View from drone of lateral western margin of sheet lobe which is visible from the entrance of the site. B. View of the lateral margin of the sheet lobe in the rainy season. Indication of typical plants. C. View of low tumulus and artificial ramp-like structure that was made to stabilize the talus. Note that the blocks used for the talus are broken pieces of Xitle lavas and provide good examples of its vesicularity and crystallinity.

Figure 25. Stop 3. A: General view of the excavation into the Technosol filling the space between the pedregal and the road. Picture taken on May 3, 2022. B: Stratigraphic column of the technosol. It is 18 cm deep (horizon Ah), with accumulation of organic matter, neutral pH, subangular structure and high amount of pores. It is a sand and silt material with a large number of stones, that does not show pedogenetic processes.

the west side (to the left), we observe a cut through the lava and its natural soil above, and on the east side (to the right) there is a *ca.* 1.6 m cut through the artificial soil that fills-in between the lava outcrop and the road (Figure 25B). These two contrasting types of soil (natural *vs.* anthropogenic) allow us to explain the ecosystem services provided by the natural lava soils.

The lavas around the Geopedregal have been covered with anthropic materials introduced in the early 1970's to build the green landscaped areas of the university covered with lawn, where Technosols (FAO) are developed that are now at least 1.5 m thick. The parent materials of this soil are of anthropic origin and correspond to construction waste of different sizes, which were used to build the sidewalks of Ciudad Universitaria. At this site, it is likely that there have been at least two building events, the first two horizons (2C-3C) appear to be younger than the rest of the profile (4C) (Figure 25B). The main pedogenetic processes are the accumulation of organic matter in the superficial horizon (Ah) and the formation of a subangular structure (Figure 25B).

In this soil, the roots of trees, shrubs and grasses can penetrate up to the first 16 cm (Figure 25B), however, at a greater depth the density increases and only plants with tap roots can penetrate and make their way into these horizons. Secondary species such as the tepozán (*Buddleja cordata*) fulfill this function and facilitate the access of species with fibrous roots. The vegetation cover of the soil is mainly made up of grass, herbaceous plants and leaf litter that comes from neighboring trees. The degradation of these materials has formed an incipient organic horizon, sufficient to favor the growth of secondary species, but not of the primary species that require greater nitrogen availability (i.e. *Quercus* spp.). The construction materials that originate these soils provide significant amounts of exchangeable bases (K, Ca and Mg), the neutral pH prevents the loss of bases by leaching, as well as the available P. Due to the fact that an important part of these soils is compacted, the water that is retained against gravity is low, fortunately an important part of it is available for plants. The ability to absorb drought in this soil is insufficient, due to its low capacity to store water.

In comparison, the age of the emplaced lava is less than 1700 years and therefore "natural" soils on it are very shallow (<4 cm) and located only in small morphological depressions, allowing almost a continuous rock surface. They contain less than 20% of fine particles and low amounts of nutrients as cations (Ca^{2}+, Mg^{2}+, K+ and Na+) but high organic matter, classifying as nudilithic Leptosol hyperskeletic distric soils by USDA (Guilbaud *et al.*, 2021; Siebe *et al.*, 2016). From the point of view of soil quality, one could say that site quality is poor: soil texture is coarse, causing excessive drainage and low water holding capacity, nitrogen retention is limited because the organic horizon is thin, but the main function of these soils is infiltration, aquifer recharge and sustaining biodiversity. The diversity in lava morphology in terms of slope, roughness, and fracture pattern, and associated soil thickness, produces high biodiversity through the crucial role of microsites (or microhabitats) (Cano-Santana *et al.*, 2006; Castellanos-Vargas *et al.*, 2017).

Stop 4: Skylights and fauna (GPS: N19°19.702', W99°10.528', 2270 m asl). At this location near the northern margin of the sheet lobe, we can observe two connected semi-circular 1.5 m-deep holes in the lava (Figure 26). Both cavities display a curved roof around them and their floor is covered by crustal fragments. An internal connection with a longer tunnel is not displayed.

Skylights are described as an opening in the roof of a lava tube that usually results from the collapse of weak points in the crust, due to a drop in the level of the internal current that previously supported the crust (Peterson *et al*., 1994). During the emplacement of the sheet lobe, it is possible that small conduits or lava tubes formed below the crust, which allowed the efficient circulation of fluid lava and its arrival towards the active margin. The drainage of these conduits after the activity (or the migration of the hot lava towards another sector of the field) probably caused the collapse by gravity of a weaker sector of the crust that previously floated on the flowing lava. These cavities have little vegetation due to the low intensity of light inside. Despite this, the largest cavity houses a tepozan tree that grew from its interior (Figure 26), and also serves as a hiding place for small mammals. The irregularity of the surface and the presence of caves in the pedregal promotes significant diversity in fauna, such as local mammals and insects (marsupial "tlacuache" *Didelphis virginiana*, ringtail "cacomixtle" *Bassariscus astutus*, rodent "ratón piñonero" *Peromyscus gratus gratus*, and the endangered bat *Leptonycteris curasoae*).

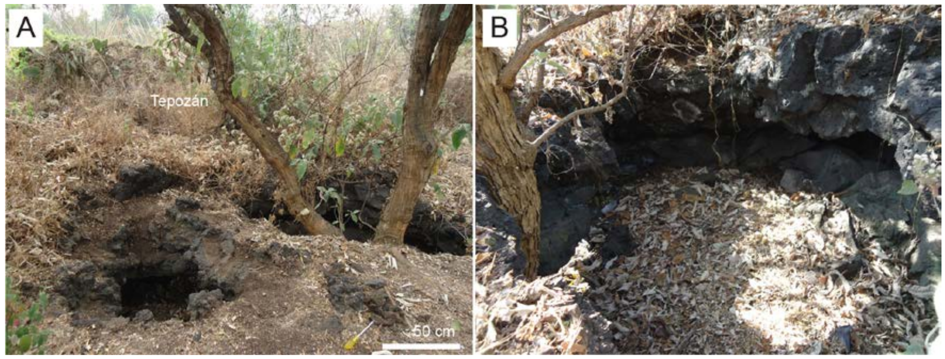

Figure 26. Stop 4. Skylights. A. View of the two cavities separated by a bridge of lava crust. Picture taken on February 2, 2022. B. View inside the largest cavity which host a tepozán tree. Pictures taken on March 3, 2023.

Stop 5: N tumulus, pollinators (GPS: N19°19.715', W99°10.528', 2272 m asl). The Geopedregal contains, in its northern tip, a mound that is approximately 3 m high. It has an elongated shape in an approximate E-W direction and reaches 19 m long and 16 m wide (Figure 27A). It is asymmetrical and taller and narrower towards its eastern end. The mound has a main cleft that follows its main axis and hence runs east-west (axial crack, Figure 27B) and several smaller, branched clefts located on the sides or flanks of the mound (radial cracks). These inflation cracks have "zig-zag" shapes and it is easy to see that both sides of the cracks match perfectly and correspond to an opening in the crust. The northern slope of the tumulus presents a lateral, sub-horizontal crack near the base that forms an elongated cavity, while the southern slope presents several large

Figure 27. Stop 5. A. General view of the *ca*. 3-m-high tumulus at the Ntip of the Geopedregal site. B. View of axial cleft from the east end, looking west. Note ropy textures on lava at the foreground and tree (pirul) growing out from cleft.

cavities (caves) to the east and a series of lateral cracks. A flat lobe with ropy texture emerges from the southwestern side of the tumulus (Stop 6).

A colony of bees established itself in the axial crack, taking advantage of the large vesicles in the upper part of the walls. Probably several mammals live in the main crack, evidence of this is their droppings that have been found. The tallest tree (*pirul*) grow in the axial crack, which is the deepest (>1 m). Its roots penetrate deeply into the crack and could even have opened it further during the growth of the tree, favoring the accumulation of organic matter inside and the infiltration of rainwater into the porous rock. The radial cracks on the flanks of the mound, on the contrary, present smaller shrubs (tepozán), probably related to their shallower depth. These cracks are also very important for fauna.

Stop 6: Ropy lavas and latrine (GPS: N19°19.710', W99°10.534', 2271 m asl).
This area consists of a low-standing sheet lobe of approx. 24 m² with complex ropy features, that emerges from the SW side of the previously described tumulus (Figure 28). The ropy lava textures indicate that this lobe was formed by hot, very fluid, gas-rich lava, probably early in the formation of the tumulus. Pahoehoe lavas can take capricious forms, the most typical being known as corded lava, which is very common in distal Xitle lavas (Badilla Cruz, 1977). It originates because when emerging to the surface, the lava cools rapidly on its surface, forming a thin crust or skin that has a plastic behavior allowing it to deform while the lava continues to flow. As the flow advances, a series of folds parallel to the flow direction are generated (Gregg *et al*., 1998).

Although corded lavas are observed on almost all exposed surfaces in the Geopedregal, these structures are easily accessible and well exposed in this site, that is, there is not much established vegetation that prevents their observation, which allows us to appreciate their morphological complexity as well as their beauty. and ecological importance, thanks to the fact that there is practically no soil formation (Figure 28). The area is a place with high solar incidence because it is a flat site and the few trees present are small, so there is little shade. The accumulation of seeds that come from the droppings of mammals that live in the Geopedregal (opossum) promote the spreading and growth of plants.

Stop 7: Artificial wall and lava cooling and degassing; saxicolous communities (GPS: N19°19.694', W99°10.540', 2270 m asl).
In the Geopedregal there are natural walls whose origin is due to the opening of the lava crust due to expansion of the lobe by internal inflation, and artificial walls which are derived from anthropogenic processes. In this stop, an artificial cut exposes the vesicular upper crust of the sheet lobe down to its dense core (Figure 29A).

Pahoehoe-type basaltic lavas are very hot when emitted; their surface cools quickly but their interior takes a long time to solidify (Hon *et al*., 1994). Consequently, there is a variation in vesicular and crystal textures from the outer part (crust) to the inner part (core) of the flow, which is due to an increase in solidification time. In all the walls or sections through them it can be seen that the lava contains abundant cavities inside called vesicles (Figure 29B). Those result from the loss of gas and the formation of bubbles within the flowing lava, which were trapped when it solidified. This gas derives from the escape of water vapor (H_2O), carbon dioxide (CO_2) and sulfur dioxide (SO_2) from the fluid lava (Walker, 1993). Since the density of the gas is lower than that of lava, the bubbles rise towards the top and hence the rock is very porous in the superficial part of the lava, with many small vesicles and some larger ones, which increase in size and decrease in abundance with increasing depth; the largest gas bubbles are formed by coalescence, which results from the fusion of several bubbles in contact.

In this wall, it can be seen that the upper part has a high number of small vesicles and the lower part is depleted of vesicles and these are larger. Vesicles have important ecological functions. First, they favor the infiltration of water into the rock and its retention, allowing the recharge of shallow aquifers in the area (Canteiro *et al*., 2019). Also, vesicles support biodiversity. The largest ones on the walls of the N tumulus serve as a niche for bees; lizards are also commonly observed in small cracks that form in the lava during cooling joints. These cooling cracks also serve as receptors for water, sediment, and organic matter, thus allowing the growth of small plants on the walls (ferns, *"oreja de burro"* meaning donkey's ear). Directly on the wall, microbial crusts (lichens) are also formed, which are of great ecological importance since they are the first colonizers of rocks and initiate pedogenesis (Cano-Santana & Meave, 1996).

Sites around the Institutes - Geopath
Around the Institutes of Geophysics, Geology and Geography there are several lava outcrops that have distinct sizes and attributes, in terms of geological and biological elements as well as their type and degree of management. In contrast to the Geopedregal site, none of these sites have been ecologically restored, and they are submitted to many threats. We have designed a geotrail to visit those outcrops (Figure 30). This tour takes about 1 hour, with explanations and discussions in the different stops.

Stop 1: Garden between the Institutes of Geology and Geophysics (GPS: N19°19.629', W99°10.579', 2270 m asl).
This is a small lava outcrop (250 m²) formed by two tumuli structures dissected by deep cracks and showing a fine surface of corded

Figure 28. Stop 6. Ropy lavas. The lavas form here a relatively thin (<1 m thick) sheet lobe with planar surfaces and a high diversity of folds, from simple (one generation) to complex (several generations; twisted forms). Pictures taken on April 24, 2022.

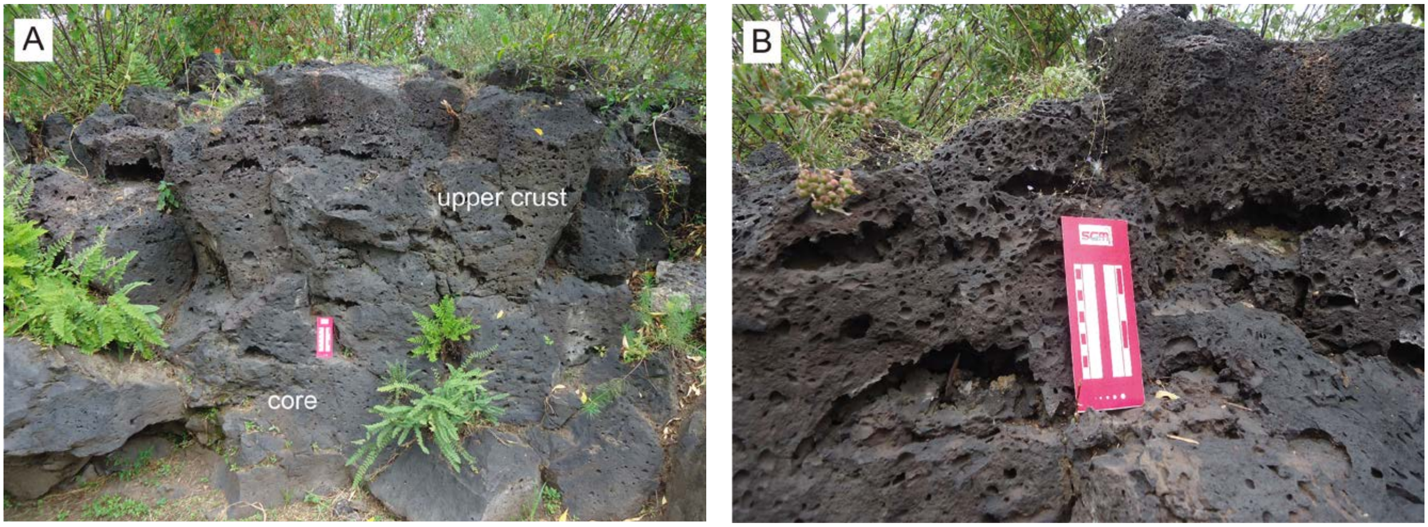

Figure 29. Stop 7. A. Section across a lateral margin of the sheet lobe that shows the highly-vesicular upper crust and denser core. B. Close up on the upper crust that shows the abundance in vesicles and their varied shapes. Note the ferns that grow in cracks (cooling joints). Pictures taken in January 2018.

lava (Figure 31). Tumuli originated by the uplift of the rigid outer crust of the lava due to internal inflation during emplacement, like a bread in the oven. In this site we find both native and exotic plants, the latter being of ornamental use. There are local and exotics trees of tepozán, fresno (*Fraxinus uhdei*) and pirul (*Schinus molle*) which are the most common in this area. This place is managed all year by gardeners and receives some irrigation. It is threatened by an invasion of ornamental "pasto kikuyo" (*Pennisetum clandestinum*) and the accumulation of garden waste.

Stop 2: Entrance of the Institute of Geology (GPS: N19°19.668', W99°10.561', 2270 m asl)

This lava outcrop has an approximately square shape and occupies an area of 460 m² (Figure 32A). It consists in a series of tumuli that have an elongated shape, and have deep, subvertical cracks that form lava walls. These walls typically show sub-horizontal striations (Figure 32B) that probably resulted from incremental opening of the crack into the viscous lava interior. The lava surfaces vary from smooth to corded (or folded) (Figure 32C) and are subdivided into m-size crustal plates separated by shallow cracks.

This site is located on the N side of the three-storey building of the institute whose edifice provides significant shade all year round. There is, in addition, an irrigation

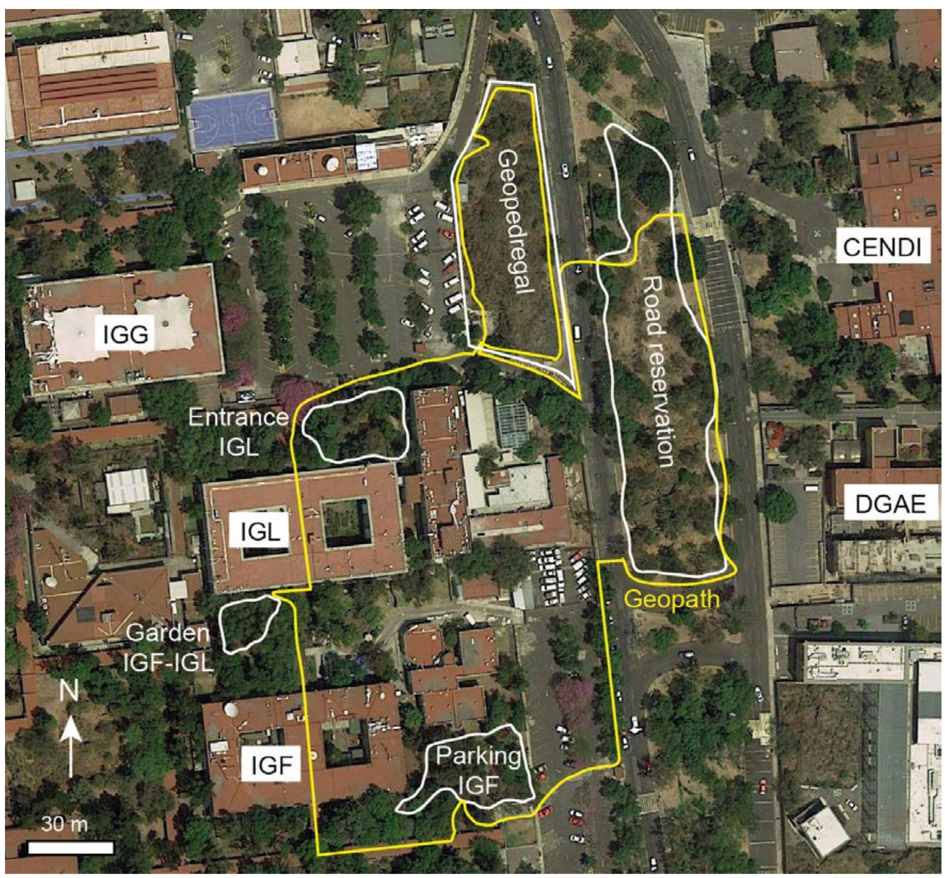

Figure 30. Geopath around UNAM´s "Geo" research institutes: IGG= Geography Institute, IGL= Geology Institute, IGF= Geophysics Institute. Other agencies are the CENDI (kinder garden) and the DGAE (organism in charge of delivering diplomas). Satellite image from Google Earth.

Figure 31. Photographs of the pedregal between institutes of Geology and Geophysics. A. Tumulus forming the northern part of the outcrop. Note the growth of trees in the axial crack. Pictures taken on April 27, 2022. B. Fine ropy or corded lava texture shown by an uplifted plate on the northern side of the site. Pictures taken on April 21, 2023.

system and a high density of trees (3.2 individuals/m² in average), hence the environment is humid and fresh. Temperatures of 20 °C were registered in the site, compared to 40 °C in the neighboring parking lot in May 2022. For this reason, this outcrop features lichens, especially on the lava walls, and different species of fens. Nevertheless, there are also several ornamental plants that were introduced by the gardeners and are an issue for the preservation of the native species. The cohabitation/competition between native and exotic plants sometimes results to be an issue for the preservation of native species. Another issue is the accumulation of gardening waste in depressions in this site which gradually bury the lava structures. Such as in the other sites, there is evidence for the transit of animals such as squirrels, birds, cacomixtles and tlacuaches in addition to dogs and cats which are harmful to the original ecosystem.

Stop 3: Ring road central reservation ("camellón") (GPS: N19°19.640', W99°10.499', 2274 m asl)

Crossing the road that runs along the eastern margin of the Geopedregal site, there is a large (5003 m²) semi-rectangular area that consists of a large and low-standing lava rise plateau (or sheet lobe) on the northern side and a *ca.* 2 m-high lava rise on the southern

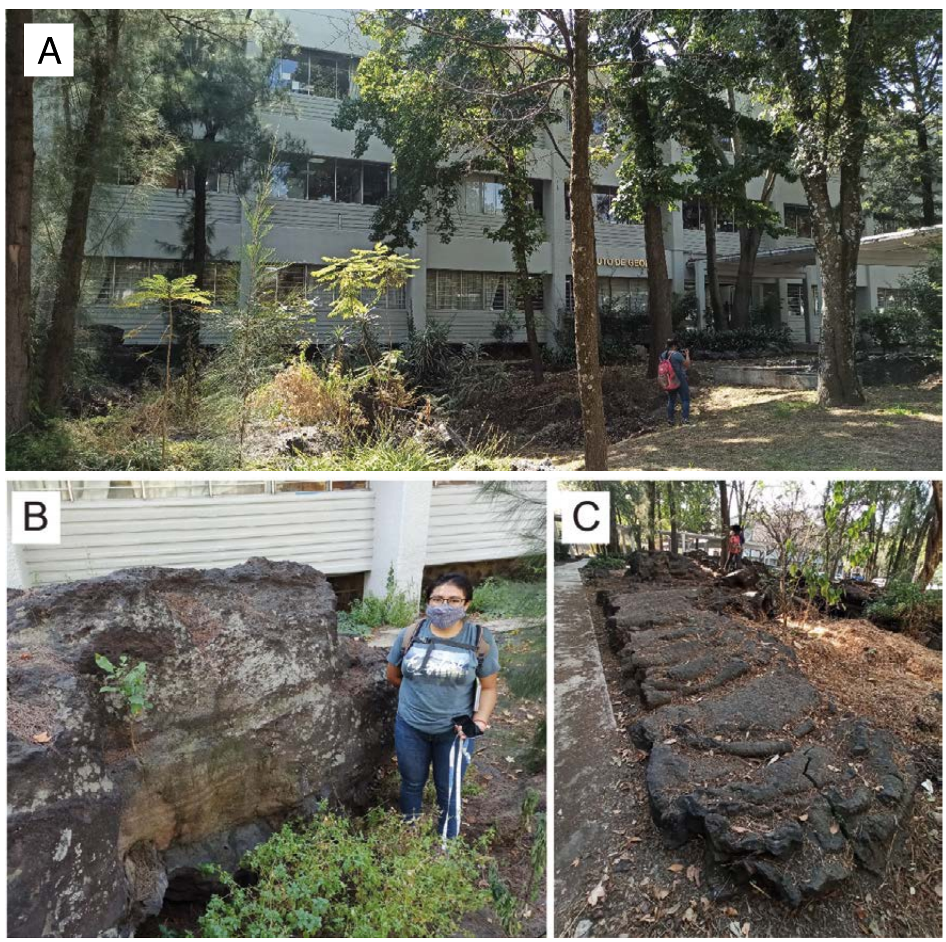

Figure 32. Photographs of the pedregal at the entrance of the Institute of Geology. A. General view of the site from the nearby parking lot. Note the numerous trees that give quasi permanent shade to the space. B. Vertical wall from the axial crack of an elongated tumulus structure. Note the pronounced striation that is parallel to the upper surface. C. Fine ropy or corded lava texture of a lobe which was emitted from the side of the tumulus, on the SE corner of the site. Pictures taken on December 1, 2021.

side (Figure 33A), which are separated by a depleted area that can be named lava rise pit following Walker (1991).

This site displays a high geodiversity (deep cracks, Figure 33B, extensive areas of ropy lava; verticular cuts along the road) and a biodiversity of native species (nopal: Figure 33C, tepozán, palo loco, agave, oreja de burro, among others). However, there are also abundant exotic species (pasto kikuyo, ricino-castor bean, *Ricinus communis, leonotis-christmas candlestick, Leonotis nepetifolia*). A temperature of 45ºC has been measured in May in the center of the sheet lobe, in comparison with 20 ºC inside the cracks.

Because of its high accessibility and lack of management by any institution, this site is subject to multiple threats and misuses (vandalism, used as a public bathroom, shelter for homeless people, accumulation of garden waste in cracks and lava rise pit etc.). It is considered unsafe by the community. A recent initiative of rehabilitation of this site led by the COUS (commission for the sustainability of the university) and in which participate the surrounding institutions, is yielding results, mostly due to the organization of monthly cleaning days.

Stop 4: Parking lot of the Institute of Geophysics (GPS: N19º19.597', W99º10.542', 2273 m asl)

This rectangular medium-sized site (883 m^2) shows a planar surface with corded lava and billowy features (Figure 34A) that are nearly entirely colonized by biological

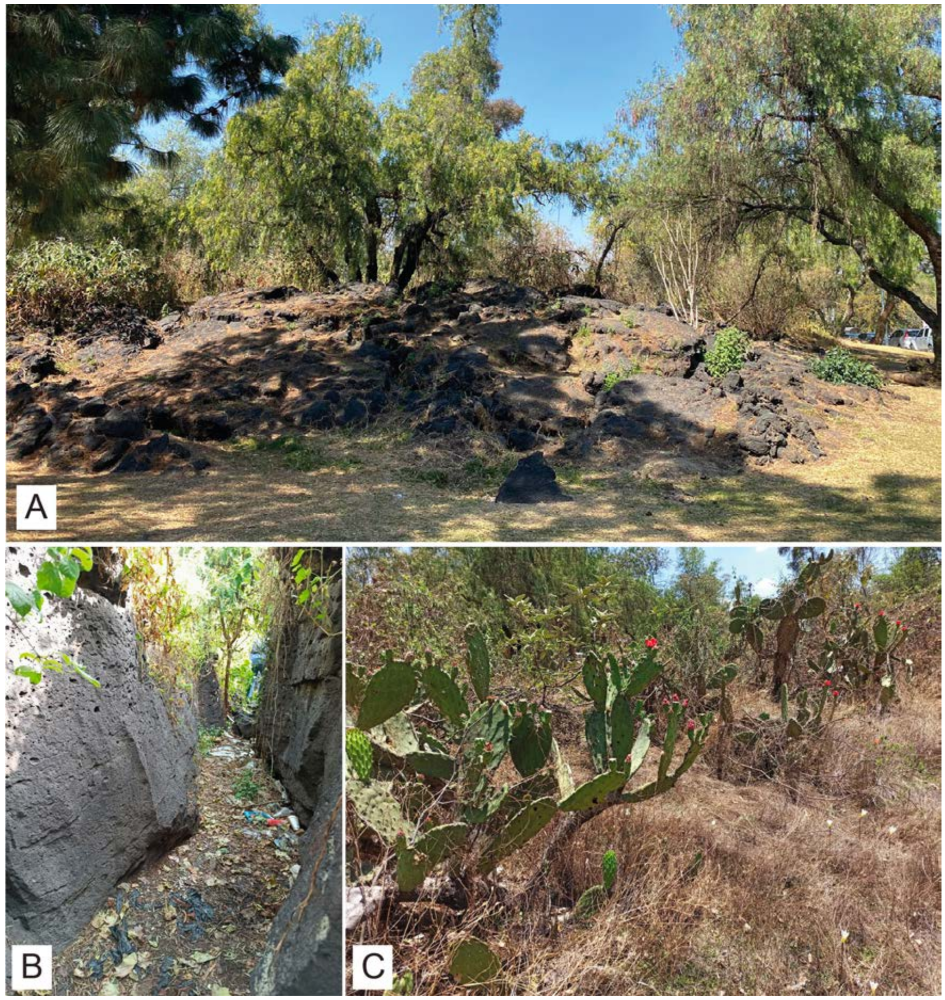

Figure 33. Photographs of the "pedregal" in the road reservation. A. General view of the tumulus in the southern side of the pedregal. This site was cleaned recently. Note the tall tree (pirul) sticking out from the summit of the tumulus, rooted in the deep axial cleft. B. Deep inflation cleft inside the tumulus, which is accessible from the road and where the internal vesicular structure of the lava can be observed closely. Unfortunately, it contains a thick basal layer of trash and used as public bathroom by the campus' taxi drivers. C. Surface of the lava rise or sheet lobe in the northern part of the pedregal, where cactus (nopal) grows happily thanks to abundant sunlight. Note also the mayitos flowers on this picture. Pictures taken on April 27, 2022.

Figure 34. Photographs of the "pedregal" near the parking lot of the Institute of Geophysics. A. General view of the site from the cemented, roof-covered path leading to the entrance of the Geophysics building. Note the numerous trees that give quasi permanent shade to the space, and the coverage of the lava by pine needles. B. Nice ropy or corded lava texture covered with Saxicola crust and with mayitos. Note that these pictures were taken after the gardeners had cut the grass. At the time of the excursion this site will be overgrown with dry vegetation, making it harder to see the lava textures but preserving the orchids from destruction. Pictures taken on April 27, 2022.

saxicola crust (Figure 34B). There is a system of shallow (<20 cm deep) cracks and a 40-cm-high artificial cut across the lava crust at the side of the institute building. This tree-covered site hosts fresnos, cedros (*Cedrus* sp.), pine-trees (*Pinus* sp.), among others. There are few typical vegetation and some ornamental gardenings species. There are abundant native species such as mayitos (*Zephyranthes* spp.) and terrestrial orchids.

CONCLUSIONS

Despite being one of the most populated and urbanized areas on the planet, Mexico City still preserves geological and archaeological sites of great value in what corresponds to the products of the eruption of Xitle volcano and its effects. The geosites visited on this excursion have scientific, aesthetic, educational, touristic and environmental conservation values. They allow us to observe the products of a recent volcanic eruption and reflect on the positive and negative impacts of volcanism on human development and the environment. It is worth noting that a new eruption of this type is a probable event in this area (Siebe, 2000; Siebe *et al.*, 2004), so that it is important to raise awareness on this phenomenon amongst the local population (Guilbaud *et al.*, 2021).

It stands out that:

1) A large part of the information presented in this guide is the result of ongoing research and may be re-evaluated in the future: scientific research is a work in progress and many sites have not been investigated in detail.

2) The focus of our work towards the study and valuation of geoheritage has led us to consider the various aspects that affect it, such as geodiversity, biodiversity and cultural heritage. The integration of the distinct disciplines represent an enriching experience for our research and teaching duties, but it is also key to organize rich and entertaining field excursions.

3) The sites visited have a very limited tourist infrastructure. Several of them have a perimeter fence that allows access to be controlled, but the area of the cone does not currently have access regulation mechanisms. At this site, we have observed an illegal urbanization that has negatively transformed the immediate surroundings of the volcano in the last 15 years, despite the denomination of this area as a conservation area by the authorities. Clearly, someone does not fulfill its functions.

4) By organizing excursions that are open to the general public, we have realized the great interest that a sector of the local population has to get to know their environment better and connect with nature and science, in addition to presenting a true interest and commitment in environmental conservation. The local inhabitants are particularly interested in learning about local volcanoes and the volcanism in general, which represents an advantage to raise their awareness on this topic and may allow to increase their resilience to the hazards that they represent.

Based on these observations, we strongly recommend the development of a comprehensive strategy for research, protection, and dissemination of the geoheritage of Mexico City, adopting a multidisciplinary and social vision, for the good of society as a whole.

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